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Chapter 4 Update: Effects of Climate and Land Use on Index Stock Recruitment

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Abstract

This update describes work on Chapter 4 since the October 1996 PATH workshop. The models and data have undergone several major revisions. First, instead of using the North Pacific index (NPI) and coastal upwelling data as indices of ocean conditions, we used summer/winter sea surface temperatures and spring/fall transition dates in the first year of ocean residence as indicators. Second, we included land use data on fire, grazing and logging that became available for approximately half of the index stocks. Models estimated using logging information are presented as examples; we expect to have land use information for 4-6 additional index stocks shortly. Third, the models are estimated using GLM techniques that are statistically identical to those used in most of the models described in Chapter 5. This will simplify the use of the models in a Bayesian prospective analyses. Finally, we have made some ad-hoc estimates of the effects of autocorrelation in the independent variables and in residuals on the degrees of freedom for tests of significance and on the precision of estimated parameters.

Introduction

When the models in Chapter 4 were last revised in the fall of 1996, several issues were noted by reviewers, and potentially important data were unavailable at the time. These included the following items:

1. Use of alternative ocean indicators. Reviewers suggested the use of sea surface temperatures and upwelling/downwelling transition dates instead of the North Pacific Index (NPI) and spring upwelling in the year of ocean entry.
2. The use of recruitment data divided by age class was questioned by some reviewers, who felt that it might not have the degree of independence assumed in the 1996 analysis.

3. No land use data were yet available, due to slow response times of land management agencies to requests for detailed land use information.
4. The potential for autocorrelation in the independent variables had not been fully addressed in past analyses.

In addition, the lead author became concerned that the models we had constructed could not readily be adapted to prospective analyses, intended to project probabilistic outcomes of population viability and stock responses to management actions. Finally, updates to the spawner-recruit data series for the Snake and Lower Columbia stocks became available last December and updates for the mid-Columbia stocks, later this spring.

Therefore, we have made several revisions to the data and analytical framework. First, land use data are now available for approximately half of the index stocks. We present results for logging as an example. Second, we substituted new ocean indices for the NPI and upwelling index. Our further examination of the age-specific recruitment suggested that the recuits by age class were indeed strongly (though far from perfectly) correlated, so we have not estimated age-specific models for this round of analyses. Third, we modified the statistical models, to make them compatible with the linear framework employed in most of the Chapter 5 analyses. Fourth, we have made some ad-hoc adjustments for the reduction in degrees of freedom and parameter precision for a subset of the models.

Based on comments we have received on an earlier draft of this document, it is important to keep several caveats in mind while reviewing the models and results. Perhaps the most important is that while the climate indices we employ appear to be strongly associated with changes survival for many stocks, the indices used here a only a small subset of those that one might use. We chose our particular indicators based on data availability, reviewers' comments on earlier versions of the models, and results of studies of tagged Snake River chinook, but there are undoubtedly many other indices that would also fit the data well. The second is that there are very few published examples of closely related studies that one can use for guidance. Although there is a fast-growing literature on salmon *abundance* (especially harvest) and climate indicators, work on salmon *survival* as a function of climate is still in its infancy. This applies particularly to chinook: since catch is modest in comparison to pinks, chum, sockeye, and other species, chinook have received relatively little attention. If one further limits the scope to wild chinook survival, the field narrows even further. For example, the review by Bradford (1995) found no direct estimates of wild chinook smolt-to-adult survival. Therefore, one should view the results as an initial foray into an area that is still some years away from maturity. Finally, it is obvious that we are representing extremely complex, imperfectly understood survival processes with models that are quite simple: extended Ricker models, with at most 6 climate terms for each stock, beyond the Ricker “a” and “b” parameters. The models generally do well for fitting available data, but they should be viewed as hypotheses – tests for patterns -- that perform well when challenged by data, not as perfect representations of what has happened to Columbia chinook stocks over the past several decades.

Data

Data used are similar to those in the 1996 version, as shown in **Table 1**. We used the drought index as our only climatic index during the year of subbasin rearing, because it was available for all subbasins and years, unlike other indices. The spring and fall transition dates were taken from earlier work by Hinrichsen (Hinrichsen *et al*,1997). Based on recoveries of coded-wire tagged spring chinook (Paulsen and Fisher, 1997), different sea surface temperatures were used for the Snake (a location offshore from the Oregon/California border), than for the lower and mid-Columbia stocks (offshore from the southern coast of Vancouver Island). Migration corridor flows from USGS gaging stations in the Snake, mid-Columbia, and lower Columbia were used instead of flow measured at mainstem dams, so that a longer time series of flows could be used than in the 1996 version. Logging is expressed as yearly percentages of spawning/rearing watershed areas that were harvested.

To compare their effects among stocks, all covariates, except the number of spawners and the number of dams in the migration corridor, were standardized to mean 0 and unit variance for brood years 1952-90. Note that this does not suppress variations among regional climate indices (for example, **Figure 1** for the drought index). If data were missing for some portion of a series, the “gaps” were neither included in the standardization nor were they “filled” in any way for the analysis. The result was that, for the land use data, there were many missing values (**Table 2**). **Table 3** contains the few correlations with an absolute value > 0.5 among the independent variables. Three presumably spurious correlations were found between percentage logged and the climate indices. In addition, the drought index is correlated with migratory corridor for several index stocks. For the drought index, we used an average of the monthly drought indices from April in the first year of subbasin rearing (after the eggs have hatched) through March in the year of downstream migration. This captures the subbasin hydrology during roughly 75% of the time the fish reside in freshwater. We employed this (despite a moderate degree of autocorrelation) because our work with over-wintering survival of PIT tagged parr (Paulsen et al. 1997) suggested that climatic conditions up to the time of downstream migration may influence parr-to-smolt survival. Finally, as already noted, the spawner-recruit data were revised for some stocks, and we incorporated the most recent (May 28, 1997) revisions for the mid-Columbia stocks.

One concern that some reviewers have raised concerns the potential for trends in the climate variables that may, simply by chance, parallel trends in index stock survival. For example, if migration corridor flows show a gradual downward trend, or alternatively a marked decrease in the mid-70's, one might expect to see significant, positive regression coefficients for flow purely by chance. Figures 1-4 display the data for the drought indices, migration corridor flow, sea surface temperatures, and the seasonal transition dates. While we have not conducted any formal tests for trends in the data, few if any long-term trends are apparent from inspection of the graphs. However, some cycling over periods of perhaps 10 years appear for some of the indices. To address this properly (with intervention analysis, for example) would require considerably more data than the available period of record for some of the indices (for example, the Snake flow data we employ begins in the mid-1950's). Furthermore, it is not clear what the implications would be for the index stock analysis if such decadal cycles exist, since the stock-recruit data only extend for 20-40 years. We would appreciate comments on this from the reviewers.

Methods

The methods employed were similar to those used in Chapter 5. The general form of the model is:

$$\ln R(t,i) = \ln S(t,i) + a(i) - b(i)S(t,i) + c(1)X(1,t,i) + \ldots + c(n)X(n,t,i) + d(1,r)Z(1,r,t) + \ldots$$
$$+ d(n,r)Z(n,r,t) + e(1)U(1,t) + \ldots + e(n)U(n,t) + e(t,i) \qquad \text{Eq. (1)}$$

where:

t indexes brood year;
i indexes stock;
r indexes region (Lower Columbia, Snake, and mid-Columbia);
$R(t,i)$ = Recruits to Columbia River mouth, brood year t, stock i;
$S(t,i)$ = Spawners, brood year t, stock i;
$\ln S(t,i)$ = Natural log of spawners, brood year t, stock i (offset equal to 1 in GLM);

a(i) = estimated Ricker "a", stock i;
b(i) = estimated Ricker "b", stock i;
c(1) … c(n) are the estimated effects of stock-specific environmental factors X($1,t$) .. X(n,t);
d(1) … d(n) are the estimated effects of regional environmental factors Z($1,t$) .. Z(n,t);
e(1) … e(n) are the estimated effects of basin-wide environmental factors U($1,t$) … U(n,t); and
$e(t,i)$ = error term, assumed to be distributed N $(0,\sigma^2)$, IID.

The model thus allows for estimation of conventional Ricker parameters [a(i) and b(i)], stock-specific environmental effects [c(1) … c(n)], regional effects [d(1) … d(n)], and universal effects [e(1) … e(n)][1]. Like most of the models in Chapter 5 (e.g., Model 1), it is strictly linear in its parameters, and so can be estimated with a variety of software packages (we used SAS© PROC GENMOD for this analysis).

The models estimated are described in **Table 4**. **Model 1** is a basic Ricker model, with the addition of N_DAMS, the number of dams in the migration corridor. **Models 2-4** add flow in the migration corridor, the drought index, and the ocean indices. **Model 5** is a variant of Model 1 from Chapter 5, which uses the number of mainstem dams in the lower Columbia, and "μ" effects for each year for the mid-Columbia and Snake, to account for the differences in recruitment patterns among regions. **Models 6A-6C** are similar to **Model 4**, but add the percentage of each subbasin logged each year. Each of the three uses a different parameterization for the percentage of the land logged each year (PERTIMBR): a single Columbia-wide parameter, one parameter for each of the three regions, and one parameter for each of the nine subbasins for which we have logging data.

We also performed two ad-hoc time series diagnostics and corrections, for autocorrelation in the independent variables and in the model residuals, for models 1-4.[2] To diagnose autocorrelation in the independent variables (IVs), we calculated the effective degrees of freedom for each IV using the following equation from the Botsford and Paulsen update to Chapter 2:

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[1] Note that the use of the "n" subscript should not be taken to mean that the same number of parameters would necessarily be estimated for each class of effects (subbasin, regional, and universal).
[2] The two types of autocorrelation are related, but distinct from one another. Autocorrelation in the independent variables may reduce the number of degrees of freedom for significance tests, though we have not seen the problem treated in quite this way for regression models. Autocorrelation in the

$$\frac{1}{N*} = \frac{1}{N} + \frac{2}{N} \sum_{j=1}^{10} \frac{N - j}{N} r_{xx_{0,j}} \qquad (2)$$

Using the results from this relationship, we then reduced the corresponding degrees of freedom proportionately for the "t" tests performed, from the usual n-k-1 to (approximately) N*-k-1, where n is the number of observations and k is the number of estimated parameters, and N* is calculated from equation 2. As an additional sensitivity, we also reduced the degrees of freedom in the "t" test by larger amounts (see next section for more details). To address autocorrelation in the residuals, we calculated the 1st-order serial correlation in the residuals for each model. We then multiplied each parameter's standard errors by 1/(1-p), where p is the estimated autocorrelation for the model. The method follows Kelejian and Oates (1974), and is in the spirit of the correlation OLS method of Bence (1995). In his simulations, Bence's method gives reasonably good coverage for the degree of autocorrelation found in our data.

Both of these methods are obviously quite crude, and we would appreciate comments from reviewers on methods to improve both the diagnostics and the corrections. The problem is complicated by the fact that we have cross-sectional time series data (for the 16 index stocks), and the series are of unequal length for many of the stocks. In addition, as we acquire more land use data and estimate models that include them, we will be faced with missing values for some of the subbasins and (probably) some years within subbasins. We are familiar with cross-sectional time series methods for well-behaved series of equal length with no missing values, but not for messy data of the sort we have for this analysis.

Results

In our discussion, we focus primarily on Models 1-5, since the results from Models 6A-6C are based on only 9 of 16 index stocks. Results for these models have several features in common. First, they all fit the recruit data very well, explaining over 97 percent of the overall variance. Second, the parameters for the Ricker "a" and "b", number of dams in the migratory corridor, and migration flow are almost always significant. The only notable exception to this is for the mid-Columbia (Entiat, Methow, and Wenatchee), where the Ricker "b" is often insignificantly different from zero.

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residuals, on the other hand, is treated extensively in econometrics, and it is well known that it may reduce estimates of standard errors and so increase the likelihood of rejecting the null hypothesis.

The goodness-of fit measures (**Table 5**) show that adding climatic variables (migration corridor flow, drought index, and ocean conditions) produces a noticeable reduction in the sum of squares, from 397 in Model 1 (no climatic variables) to 294 in Model 4 (which includes all the climatic variables with regional parameters). Among Models 1-4, Model 4 has the lowest Aikaike Information Criteria (AIC) of 1252, while Model 3 (Model 4 without the ocean indices) has the lowest Bayesian Information Criteria (BIC) of 1453.[3] We also estimated Model 5, which has no climate variables, but does include Chapter 5-type μs for the Snake and mid-Columbia. This clearly provides the best fist to the data, with a sum of squares of about 159 (133 lower than Model 4), and the lowest AIC and BIC scores among the 6 models. Model 5 accounts well for differences among the three regions (Lower Columbia, mid-Columbia, and Snake) precisely because it does not ascribe those differences to any particular covariates.

Details of the parameter estimates for Models 1-6 are shown in **Table 6-14. R**ather than focusing on the details, we instead examine a subset of the parameter estimates for dams and climate in Models 1-4. These are shown in **Table 15**. The N_DAMS parameter is estimated for all five models. As one might expect, it is significant and negative in all models, and the magnitude of the coefficient does not vary much, from about -0.41 to -0.36. Migration corridor flow is always significant and positive for the mid-Columbia and Snake stocks in the models where it appears, but the magnitudes of the coefficients vary a bit more than for N_DAMS, from 0.37-0.47 for the mid-Columbia, and from 0.16-0.37 for the Snake. Migration corridor flow is significant for the lower Columbia stocks only in Model 4.

The drought index is significant and positive for the mid-Columbia and Snake stocks in all models where it appears (Models 2B, 3, and 4)[4]. The index ranges from 0.36-0.54 for the mid-Columbia stocks, and from 0.27-0.41 for the Snake stocks. The spring transition date is never significant, while the fall transition date is significant only for the Snake stocks. Sea surface temperatures are significant (and negative) for the mid-Columbia and Snake stocks. This suggests that higher ocean temperatures are associated with lower survival. Recalling that the climate indices have all been standardized to (0,1), it is interesting that their coefficients are all the same order of magnitude.

[3] The lower the AIC or BIC, the better the model fits that data, after accounting for the number of model parameters. The AIC gives less weight to the number of parameters than the BIC.
[4] Recall that the index is the excess of precipitation over evaporation, so a negative index value is associated with below-average water availability.

This suggests that they all have roughly the same degree of influence on recruitment for the upriver stocks. The normality plot for the Model 4 residuals (**Figure 5**) shows some modest skew at the upper and lower ends, but no gross departure from normality.

We are also interested in how the μs from Model 5 compare to the differences in upstream/downstream recruitment from the climate models. **Figures 6A** and **6B** compare this for Model 4 (the fully specified climate model) for the Snake and mid-Columbia, respectively. Note that a higher value of μ is associated with lower upriver recruitment. For both upriver regions, the climate model shows approximately the same pattern as does Model 5. However, Model 4 does not capture some “extreme” events, such as the dip in upriver recruitment for 1990 for both upriver regions, or the 1972 reduction for the Snake stocks. These events are obviously either associated with some factors entirely outside the scope of the climate-based models (e.g., detailed hydrosystem operations), or that are not well-represented by the regional, time-invariant climate parameters included in the climate models.

The results for logging (Models 6A-6C) are shown in **Tables 12-14**. Timber harvest has a significant effect only when parameters are estimated on a subbasin or index stock basis (Model 6C), and only for one subbasin. This sort of negative result may be due to a variety of causes, including but not limited to the following:

1. Logging truly has no effect on spawner to recruit survival, an outcome that would be of great interest to both extractive industries and their regulators.
2. Lack of data. We have no data for seven index stocks, and many years of data are unavailable for the nine stocks with some information (see **Table 2**).
3. The land use variables (e.g., logging) are being measured at too coarse a scale, as the percentage of the drainage area affected each year. We probably can obtain the data at much finer (square-mile) scales for many index stocks.
4. The effects of the land use activity in a given year are assumed to manifest themselves via parr that are rearing in the subbasin that year. Perhaps the effects are lagged in some fashion.

Federal land use agencies have promised data on 4 to 5 additional index stocks within the next few weeks. That should enable us to address (2), insofar as possible. If it appears worth pursuing, we could calculate land use impacts on a considerably finer scale (i.e., 3), albeit at some cost in time and effort. It would be trivial to try variants on (4), but there is no unambiguous way to do so, and we want to avoid problems of the "if you try 100 regressions, 5% will be significant…" variety. We would appreciate any suggestions from the reviewers on these points.

Results for time series corrections are shown in **Tables 16-18**. **Table 16** shows the average "N" and "N*" correction using equation 2. As can be seen, the autocorrelation in the IVs is most serious for the number of dams, and weakest for summer sea surface temperature. **Table 17** contains results for the ad-hoc corrections to the autocorrelation of the IVs. The first few columns simply repeat the information in Table 15, using 498-*k*-1 degrees of freedom, where *k* is the estimated number of parameters. The next few columns show the significance of the estimated coefficients using 150, 100, and 50 degrees of freedom (DOF). The reductions in DOF are of roughly 70, 80, and 90 percent of the number used in the original models. As one can see, the reduction does not affect conclusions regarding the significance of N_DAMS or of any of the climate parameters. In part, this is because the shape of the "t" distribution does not vary too much between 400+ and 50 degrees of freedom.

Table 18 displays the results of correcting for 1^{st}-order autocorrelation in the residuals of the estimated models. The standard error expansion factor is simply $(1/(1-p))$, as discussed in the methods section, where p ranges from about 0.38 for Model 1 to 0.24 for Model 4. The expanded t-ratio is the estimated parameter divided by the product of the original standard error and the expansion factor. The only change resulting from the ad-hoc correction is for the mid-Columbia winter sea surface temperature parameter in Model 5. The estimated significance of the other parameters is unchanged.

Discussion and Future Plans

As already noted, the results are preliminary, since more land use data are expected to be available shortly. In particular, we expect to have new information on the following:

1. Spawner-recruit information for 10-20 additional Snake River stocks;
2. Land use data for 4-6 more of the present 16 index stocks (total of 13-15 index stocks), and for some subset of the 10-20 additional Snake stocks noted above;
3. Subjective habitat ranking and their relationships to Eastside Assessment data which have been developed by Danny Lee and state fisheries biologists;
4. Hatchery contributions to spawning populations, and other measures of hatchery influence, which are being developed by Paul Wilson.

In addition, we would like to have spawner-recruit data from outside the Columbia River Basin, to help disentangle climate effects and river operations. Comparison of the Columbia and Snake "mus" show surprising covariation (see **Figure 7**) and we would like to see if similar covariation exists with the Willamette, Umpqua or Rogue River stocks. These data, though promised at the beginning of PATH, are still unavailable.

There are some outstanding issues regarding the existing data. Rich Zabel and Rick Deriso have been working on methods to estimate recruit age structure for years when historic data are missing or incomplete. Preliminary results for the John Day stocks (which are missing age data for 50-70 percent of the time series) suggest that this does not have a great deal of influence on the results. Again, we will incorporate either the new estimates or methods to estimate age structure within the models, as seems appropriate. In addition, we have postponed doing further outlier analysis and other diagnostics until land use data for the 4-6 missing index stocks become available. We plan to examine normality plots for the raw residuals, Cook's distance, and the "hat" matrix to check for influential points in the regression.

Finally, we reiterate the potential use of these models in prospective analyses. Because they are linear, MLE regression models, performing prospective analyses (i.e., projections of future population abundance) is straightforward[5]. We welcome your comments and questions on both data, methods, and results.

[5] See for example Gellman et al. (1995), Chapter 8.

Table 1. Variable Names, Descriptions, and Structures

Variable Name	Description	"Structure"	Missing Values
DR_AVG	Drought index 1st Winter of Subbasin Rearing-March of Year of Downstream Migration	Subbasin-Specific, based on climatic regions	None
FALDATE	Date of Fall Transition, Year of Outmigration	Universal (same data for all stocks), regional coefficients	None
MIGRFLOW	Mean Apr-June flow, Year of Outmigration	Regional (Snake, Mid-Columbia, Lower Columbia)	Missing Early 50's for Snake, Others all present
N_DAMS	# Mainstem dams, Year of Outmigration	Regional [Snake, Mid-Columbia (differs among subs.), Lower Columbia(differs among subs.)]	None
PERTIMBR	Percent Logged, Year of Subbasin Rearing	Subbasin-Specific	Many Missing subbasins/Years
RECTOTAL	Total Recruits	Subbasin-Specific	Number of Years stock-specific
SPAWNERS	Estimated Spawners	Subbasin-Specific	Number of Years stock-specific
SPRDATE	Date of Spring Transition, Year of Outmigration	Universal (same data for all stocks), regional coefficients	None
SSTSUMR	Summer Sea Surface Temperature, 1st Ocean Summer	Regional (Columbia Vs Snake)	None
SSTWINTR	Winter Sea Surface Temperature, 1st Ocean Winter	Regional (Columbia Vs Snake)	None

Table 2. Logging Data for 8 Subbasins. Data are normalized to (0,1).

	Imnaha	**Minam**	**JDA-Middle**	**JDA North**	**JDA-Upper Main**	**Klickitat**	**Wind**	**Entiat**	**Wenatchee**
Brood Year									
1952	NA	NA	NA	NA	NA	NA	NA	NA	-0.67
1953	NA	NA	NA	NA	NA	NA	NA	NA	-0.85
1954	NA	NA	NA	NA	NA	NA	NA	NA	-0.67
1955	NA	NA	NA	NA	NA	NA	NA	NA	-0.54
1956	NA	NA	NA	NA	NA	NA	NA	NA	-0.58
1957	NA	NA	NA	NA	NA	NA	NA	NA	-0.67
1958	NA	NA	NA	NA	NA	NA	NA	NA	-0.71
1959	NA	NA	NA	NA	NA	NA	NA	NA	-0.63
1960	NA	NA	NA	NA	NA	NA	NA	NA	-0.78
1961	NA	NA	NA	NA	NA	NA	NA	NA	-0.20
1962	NA	NA	NA	NA	NA	NA	NA	NA	-1.02
1963	NA	0	NA	NA	-0.43	NA	NA	NA	0.33
1964	NA	0	NA	NA	-0.70	NA	NA	NA	0.28
1965	NA	0	NA	NA	-0.70	NA	NA	NA	0.64
1966	NA	0	NA	NA	-0.65	NA	NA	NA	-0.98
1967	NA	0	NA	NA	-0.61	NA	NA	NA	-0.07
1968	NA	0	NA	NA	-0.70	NA	NA	NA	-0.72
1969	NA	0	-0.45	NA	-0.70	NA	0.07	NA	1.05
1970	NA	0	-0.45	NA	2.94	NA	-0.45	NA	-0.71
1971	NA	0	-0.33	NA	-0.70	NA	-0.29	NA	-0.81
1972	-1.09	0	-0.45	NA	-0.70	NA	-1.07	NA	0.87
1973	-1.10	0	-0.45	NA	-0.70	NA	-1.19	NA	-0.34
1974	-1.10	0	-0.45	NA	-0.70	NA	-0.79	NA	-0.44
1975	-1.07	0	-0.45	-1.55	-0.70	NA	0.27	1.94	-0.72
1976	-1.10	0	-0.45	-1.31	0.52	-1.20	-0.19	NA	-0.50
1977	-1.10	0	-0.45	-0.84	0.08	0.57	-0.02	NA	2.25
1978	0.04	0	-0.45	0.21	0.01	0.14	2.88	NA	0.03
1979	-0.43	0	-0.45	1.51	-0.70	-0.17	0.38	-0.16	-1.12
1980	0.60	0	-0.45	0.47	-0.54	-0.87	-0.41	-0.43	0.72
1981	0.07	0	-0.30	1.34	-0.70	-1.23	-0.99	-0.87	-1.01
1982	0.91	0	0.10	0.23	0.84	-1.51	-1.08	-0.58	-0.33
1983	0.54	0	-0.23	1.99	0.57	-0.89	-0.04	0	-0.17
1984	0.92	0	1.14	0.05	-0.09	0.23	0.94	-0.58	0.10
1985	0.82	0	1.52	0.24	-0.51	0.03	0.81	-0.92	2.91
1986	1.15	0	3.73	0.10	1.62	0.81	-1.15	-0.45	1.40
1987	-0.35	0	0.62	-0.26	0.56	1.11	0.81	-0.15	2.33
1988	1.68	0	-0.45	-0.58	0.89	0.77	0.13	-0.51	1.46
1989	1.56	0	-0.45	-0.68	2.54	0.15	1.73	2.24	0.13
1990	-0.96	0	-0.45	-0.94	-0.11	2.07	-0.36	0.47	0.71

Table 3. Correlations of Independent Variables [Abs(Rho) > 0.5], by Subbasin *

Index Stock	Variable 1	Variable 2	Correlation
Entiat	N_DAMS	MIGRFLOW	-0.61
Entiat	SPRTRANS	PERTIMBR	-0.70
Imnaha	DR_AVG	MIGRFLOW	0.52
John Day Mid Fk	N_DAMS	SPRTRANS	0.55
John Day Nor Fk	N_DAMS	SPRTRANS	0.55
John Day Nor Fk	PERTIMBR	DR_AVG	0.72
John Day U Main	N_DAMS	SPRTRANS	0.55
Klickitat	PERTIMBR	DR_AVG	-0.56
Klickitat	PERTIMBR	MIGRFLOW	-0.65
Methow	N_DAMS	SPRTRANS	0.61
Minam	MIGRFLOW	DR_AVG	0.52
Sulphur Creek	MIGRFLOW	DR_AVG	0.50
Warm Springs	SPRTRANS	MIGRFLOW	0.51
Warm Springs	MIGRFLOW	DR_AVG	0.50
Wenatchee	N_DAMS	MIGRFLOW	-0.60
Wenatchee	PERTIMBR	DR_AVG	-0.57
Wind River	MIGRFLOW	DR_AVG	0.61

* See Table 1 for variable definitions.

Table 4. Model Specifications

Model Number	Description
M1	Ricker "a", Ricker "b", Number of Mainstem Dams
M2A	(1) + Region * Migration Corridor Flow
M2B	(1) + Region * Average Drought Index
M3	(1) + Region * Migration Corridor Flow + Region * Average Drought Index
M4	(3) + Region * Spring Transition, Fall Transition, Winter and Summer Sea Surface Temperatures
M5	Deriso Model 1 Type "μs," 1959-90, No Year Effects
M6A	(4) + Percent Logged (Columbia-Wide parameter)
M6B	(4) + Percent Logged (Regional parameter)
M6C	(4) + Percent Logged (Stock-Specific parameter)

Table 5. Goodness of Fit, Models 1-6C.

Model Number	Observations Used	Number of Parameters	Sum of Squared Errors	Null Deviance	R-Square	AIC	BIC	Log Likelihood
M1	498	33	397.12	24768.2	0.984	1366.53	1505.48	-650.27
M2	498	36	350.84	24768.2	0.986	1310.83	1462.41	-619.41
M3A	498	36	352.49	24768.2	0.986	1313.17	1464.75	-620.58
M3B	498	39	331.54	24768.2	0.987	1288.65	1452.86	-605.32
M4	498	51	293.62	24768.2	0.988	1252.17	1466.91	-575.08
M5	498	97	158.87	24768.2	0.994	1038.30	1446.73	-422.15
M6A	192	38	92.92	8918.6	0.990	481.52	605.31	-202.76
M6B	192	40	92.70	8918.6	0.990	485.08	615.38	-202.54
M6C	192	45	89.01	8918.6	0.990	487.27	633.86	-198.63

Table 6. Estimated Parameters, Model 1 - Ricker Paramters & Number of Dams in Migration Corridor.

Parameter	Subbasin or Region	Estimated Parameter	Std. Error	Chi-Square	P > Chi-Square
Ricker "a"	Bear Valley/Elk	3.89	0.40	96.25	0.0001
Ricker "a"	Entiat	4.67	0.38	152.22	0.0001
Ricker "a"	Imnaha	3.94	0.38	107.63	0.0001
Ricker "a"	John Day Mid Fk	2.71	0.24	122.79	0.0001
Ricker "a"	John Day Nor Fk	2.69	0.38	50.19	0.0001
Ricker "a"	John Day U Main	2.97	0.30	100.26	0.0001
Ricker "a"	Johnson	3.96	0.38	107.03	0.0001
Ricker "a"	Klickitat	1.72	0.27	41.56	0.0001
Ricker "a"	Marsh Creek	3.86	0.38	101.09	0.0001
Ricker "a"	Methow	5.45	0.45	149.39	0.0001
Ricker "a"	Minam	4.23	0.35	145.32	0.0001
Ricker "a"	Poverty Flat	3.98	0.37	118.95	0.0001
Ricker "a"	Sulphur Creek	4.11	0.36	129.03	0.0001
Ricker "a"	Warm Springs	3.29	0.40	68.33	0.0001
Ricker "a"	Wenatchee	3.72	0.43	74.82	0.0001
Ricker "a"	Wind River	1.19	0.32	13.82	0.0002
Ricker "b"	Bear Valley/Elk	0.49	0.25	4.01	0.0453
Ricker "b"	Entiat	1.28	0.64	3.98	0.0461
Ricker "b"	Imnaha	0.64	0.22	8.25	0.0041
Ricker "b"	John Day Mid Fk	1.75	0.43	16.69	0.0001
Ricker "b"	John Day Nor Fk	0.52	0.21	5.92	0.0149
Ricker "b"	John Day U Main	3.43	0.88	15.29	0.0001
Ricker "b"	Johnson	2.07	0.65	10.23	0.0014
Ricker "b"	Klickitat	2.29	0.80	8.18	0.0042
Ricker "b"	Marsh Creek	0.92	0.47	3.75	0.0528
Ricker "b"	Methow	0.39	0.18	4.75	0.0294
Ricker "b"	Minam	1.53	0.33	21.55	0.0001
Ricker "b"	Poverty Flat	0.79	0.21	14.69	0.0001
Ricker "b"	Sulphur Creek	1.76	0.63	7.95	0.0048
Ricker "b"	Warm Springs	1.56	0.47	11.08	0.0009
Ricker "b"	Wenatchee	0.04	0.13	0.12	0.734
Ricker "b"	Wind River	2.75	1.31	4.39	0.0361
N_DAMS		-0.4121	0.04	130.63	0.00

Table 7. Estimated Parameters, Model 2A : Model 1 + Migration Corridor Flow.

Parameter	Subbasin or Region	Estimated Parameter	Std. Error	Chi-Square	P > Chi-Square
Ricker "a"	Bear Valley/Elk	3.82	0.38	102.10	0.0001
Ricker "a"	Entiat	4.59	0.36	160.78	0.0001
Ricker "a"	Imnaha	3.96	0.36	118.88	0.0001
Ricker "a"	John Day Mid Fk	2.69	0.23	135.59	0.0001
Ricker "a"	John Day Nor Fk	2.70	0.36	57.23	0.0001
Ricker "a"	John Day U Main	2.93	0.28	109.44	0.0001
Ricker "a"	Johnson	3.94	0.37	115.76	0.0001
Ricker "a"	Klickitat	1.78	0.25	48.91	0.0001
Ricker "a"	Marsh Creek	3.81	0.37	108.37	0.0001
Ricker "a"	Methow	5.62	0.42	178.00	0.0001
Ricker "a"	Minam	4.12	0.33	151.82	0.0001
Ricker "a"	Poverty Flat	3.90	0.35	124.87	0.0001
Ricker "a"	Sulphur Creek	4.11	0.35	141.68	0.0001
Ricker "a"	Warm Springs	3.22	0.38	72.65	0.0001
Ricker "a"	Wenatchee	3.59	0.41	77.20	0.0001
Ricker "a"	Wind River	1.22	0.30	16.43	0.0001
Ricker "b"	Bear Valley/Elk	0.47	0.23	4.07	0.0436
Ricker "b"	Entiat	1.05	0.60	3.06	0.0805
Ricker "b"	Imnaha	0.70	0.21	11.13	0.0008
Ricker "b"	John Day Mid Fk	1.69	0.41	17.27	0.0001
Ricker "b"	John Day Nor Fk	0.53	0.20	6.97	0.0083
Ricker "b"	John Day U Main	3.27	0.83	15.45	0.0001
Ricker "b"	Johnson	2.13	0.61	12.15	0.0005
Ricker "b"	Klickitat	2.41	0.76	10.18	0.0014
Ricker "b"	Marsh Creek	0.91	0.45	4.20	0.0404
Ricker "b"	Methow	0.45	0.17	7.10	0.0077
Ricker "b"	Minam	1.40	0.31	20.39	0.0001
Ricker "b"	Poverty Flat	0.74	0.19	14.47	0.0001
Ricker "b"	Sulphur Creek	1.92	0.59	10.59	0.0011
Ricker "b"	Warm Springs	1.41	0.45	9.85	0.0017
Ricker "b"	Wenatchee	-0.02	0.12	0.03	0.8602
Ricker "b"	Wind River	2.61	1.24	4.45	0.0349
N_DAMS		-0.4054	0.03	135.69	0.00
MIGRFLOW * REGION	Lower Columbia	0.12	0.08	2.26	0.1331
MIGRFLOW * REGION	Mid Columbia	0.44	0.10	19.24	0.0001
MIGRFLOW * REGION	Snake	0.37	0.06	42.90	0.0001

Table 8. Estimated Paramters, Model 2B : Model 1 + Drought Index.

Parameter	Subbasin or Region	Estimated Parameter	Std. Error	Chi-Square	P > Chi-Square
Ricker "a"	Bear Valley/Elk	3.64	0.37	94.30	0.0001
Ricker "a"	Entiat	4.31	0.36	143.56	0.0001
Ricker "a"	Imnaha	3.73	0.36	108.03	0.0001
Ricker "a"	John Day Mid Fk	2.59	0.23	126.15	0.0001
Ricker "a"	John Day Nor Fk	2.56	0.36	51.20	0.0001
Ricker "a"	John Day U Main	2.84	0.28	102.42	0.0001
Ricker "a"	Johnson	3.73	0.36	105.85	0.0001
Ricker "a"	Klickitat	1.69	0.25	45.10	0.0001
Ricker "a"	Marsh Creek	3.60	0.36	97.97	0.0001
Ricker "a"	Methow	5.00	0.42	138.69	0.0001
Ricker "a"	Minam	3.93	0.33	139.04	0.0001
Ricker "a"	Poverty Flat	3.74	0.35	117.14	0.0001
Ricker "a"	Sulphur Creek	3.83	0.34	125.02	0.0001
Ricker "a"	Warm Springs	3.16	0.38	69.01	0.0001
Ricker "a"	Wenatchee	3.28	0.41	64.39	0.0001
Ricker "a"	Wind River	1.14	0.30	14.23	0.0002
Ricker "b"	Bear Valley/Elk	0.51	0.23	4.79	0.0286
Ricker "b"	Entiat	1.04	0.60	2.96	0.0854
Ricker "b"	Imnaha	0.71	0.21	11.30	0.0008
Ricker "b"	John Day Mid Fk	1.75	0.40	18.78	0.0001
Ricker "b"	John Day Nor Fk	0.51	0.20	6.48	0.0109
Ricker "b"	John Day U Main	3.37	0.83	16.43	0.0001
Ricker "b"	Johnson	2.15	0.61	12.41	0.0004
Ricker "b"	Klickitat	2.30	0.75	9.32	0.0023
Ricker "b"	Marsh Creek	0.91	0.45	4.19	0.0406
Ricker "b"	Methow	0.31	0.17	3.37	0.0662
Ricker "b"	Minam	1.48	0.31	22.65	0.0001
Ricker "b"	Poverty Flat	0.81	0.19	17.51	0.0001
Ricker "b"	Sulphur Creek	1.71	0.59	8.43	0.0037
Ricker "b"	Warm Springs	1.50	0.45	11.28	0.0008
Ricker "b"	Wenatchee	-0.04	0.12	0.09	0.7597
Ricker "b"	Wind River	2.69	1.24	4.72	0.0298
N_DAMS		-0.3685	0.03	114.11	0.00
DR_AVG*REGION	Lower Columbia	0.08	0.09	0.78	0.3785
DR_AVG*REGION	Mid Columbia	0.54	0.11	23.67	0.0001
DR_AVG*REGION	Snake	0.41	0.07	39.08	0.0001

Table 9. Estimated Parameters, Model 3 : Model 1 + Migration Corridor Flow + Drought Index.

Parameter	Subbasin or Region	Estimated Parameter	Std. Error	Chi-Square	P > Chi-Square
Ricker "a"	Bear Valley/Elk	3.62	0.37	94.84	0.0001
Ricker "a"	Entiat	4.32	0.36	145.10	0.0001
Ricker "a"	Imnaha	3.76	0.36	110.97	0.0001
Ricker "a"	John Day Mid Fk	2.60	0.23	132.66	0.0001
Ricker "a"	John Day Nor Fk	2.61	0.35	55.90	0.0001
Ricker "a"	John Day U Main	2.84	0.27	107.26	0.0001
Ricker "a"	Johnson	3.73	0.36	107.55	0.0001
Ricker "a"	Klickitat	1.75	0.25	50.07	0.0001
Ricker "a"	Marsh Creek	3.60	0.36	99.45	0.0001
Ricker "a"	Methow	5.23	0.42	156.63	0.0001
Ricker "a"	Minam	3.91	0.33	139.62	0.0001
Ricker "a"	Poverty Flat	3.71	0.34	116.95	0.0001
Ricker "a"	Sulphur Creek	3.88	0.34	128.58	0.0001
Ricker "a"	Warm Springs	3.12	0.37	71.18	0.0001
Ricker "a"	Wenatchee	3.26	0.40	65.50	0.0001
Ricker "a"	Wind River	1.18	0.29	16.20	0.0001
Ricker "b"	Bear Valley/Elk	0.47	0.23	4.36	0.0368
Ricker "b"	Entiat	0.89	0.59	2.31	0.1289
Ricker "b"	Imnaha	0.72	0.20	12.32	0.0004
Ricker "b"	John Day Mid Fk	1.70	0.39	18.43	0.0001
Ricker "b"	John Day Nor Fk	0.52	0.19	7.22	0.0072
Ricker "b"	John Day U Main	3.25	0.81	16.03	0.0001
Ricker "b"	Johnson	2.13	0.59	12.88	0.0003
Ricker "b"	Klickitat	2.41	0.73	10.76	0.001
Ricker "b"	Marsh Creek	0.89	0.43	4.22	0.04
Ricker "b"	Methow	0.37	0.16	5.17	0.0229
Ricker "b"	Minam	1.40	0.30	21.42	0.0001
Ricker "b"	Poverty Flat	0.76	0.19	16.08	0.0001
Ricker "b"	Sulphur Creek	1.81	0.57	10.03	0.0015
Ricker "b"	Warm Springs	1.38	0.44	9.93	0.0016
Ricker "b"	Wenatchee	-0.08	0.12	0.44	0.5079
Ricker "b"	Wind River	2.58	1.20	4.60	0.0319
N_DAMS		-0.3722	0.04	112.44	0.00
MIGRFLOW*REGION	Lower Columbia	0.11	0.08	1.96	0.1617
MIGRFLOW*REGION	Mid Columbia	0.37	0.10	13.82	0.0002
MIGRFLOW*REGION	Snake	0.24	0.06	14.31	0.0002
DR_AVG*REGION	Lower Columbia	0.05	0.09	0.29	0.5882
DR_AVG*REGION	Mid Columbia	0.45	0.11	16.51	0.0001
DR_AVG*REGION	Snake	0.27	0.08	12.22	0.0005

Table 10. Estimated Parameters, Model 4 : Model 3 + Ocean Indices.

Parameter	Subbasin or Region	Estimated Parameter	Std. Error	Chi-Square	P > Chi-Square
Ricker "a"	Bear Valley/Elk	3.69	0.35	108.79	0.0001
Ricker "a"	Entiat	4.50	0.35	163.60	0.0001
Ricker "a"	Imnaha	3.81	0.34	125.66	0.0001
Ricker "a"	John Day Mid Fk	2.50	0.22	131.87	0.0001
Ricker "a"	John Day Nor Fk	2.73	0.33	66.53	0.0001
Ricker "a"	John Day U Main	2.80	0.26	115.53	0.0001
Ricker "a"	Johnson	3.74	0.34	118.94	0.0001
Ricker "a"	Klickitat	1.74	0.24	52.75	0.0001
Ricker "a"	Marsh Creek	3.68	0.34	115.49	0.0001
Ricker "a"	Methow	5.29	0.40	172.12	0.0001
Ricker "a"	Minam	3.82	0.32	144.74	0.0001
Ricker "a"	Poverty Flat	3.67	0.33	125.32	0.0001
Ricker "a"	Sulphur Creek	3.94	0.33	146.61	0.0001
Ricker "a"	Warm Springs	3.18	0.35	81.88	0.0001
Ricker "a"	Wenatchee	3.54	0.40	78.94	0.0001
Ricker "a"	Wind River	1.18	0.28	18.14	0.0001
Ricker "b"	Bear Valley/Elk	0.61	0.21	8.02	0.0046
Ricker "b"	Entiat	1.51	0.59	6.54	0.0105
Ricker "b"	Imnaha	0.82	0.19	17.90	0.0001
Ricker "b"	John Day Mid Fk	1.53	0.38	16.06	0.0001
Ricker "b"	John Day Nor Fk	0.62	0.19	10.87	0.001
Ricker "b"	John Day U Main	3.23	0.77	17.59	0.0001
Ricker "b"	Johnson	2.31	0.56	16.78	0.0001
Ricker "b"	Klickitat	2.37	0.71	11.26	0.0008
Ricker "b"	Marsh Creek	1.19	0.41	8.32	0.0039
Ricker "b"	Methow	0.49	0.16	9.57	0.002
Ricker "b"	Minam	1.33	0.29	21.43	0.0001
Ricker "b"	Poverty Flat	0.76	0.18	18.33	0.0001
Ricker "b"	Sulphur Creek	2.17	0.54	15.93	0.0001
Ricker "b"	Warm Springs	1.42	0.41	11.73	0.0006
Ricker "b"	Wenatchee	0.06	0.12	0.28	0.5956
Ricker "b"	Wind River	2.33	1.14	4.18	0.041

Table 10. (Concluded)

Parameter	Subbasin or Region	Estimated Parameter	Std. Error	Chi-Square	P > Chi-Square
N_DAMS		-0.3646	0.03	115.94	0.00
MIGRFLOW*REGION	Lower Columbia	0.16	0.08	4.52	0.0335
MIGRFLOW*REGION	Mid Columbia	0.47	0.10	21.52	0.0001
MIGRFLOW*REGION	Snake	0.16	0.06	6.74	0.0095
DR_AVG*REGION	Lower Columbia	-0.01	0.09	0.01	0.9118
DR_AVG*REGION	Mid Columbia	0.36	0.11	10.69	0.0011
DR_AVG*REGION	Snake	0.41	0.08	28.22	0.0001
FALTRANS*REGION	Lower Columbia	-0.16	0.07	4.96	0.0259
FALTRANS*REGION	Mid Columbia	-0.11	0.10	1.19	0.2747
FALTRANS*REGION	Snake	-0.27	0.06	20.15	0.0001
SPRTRANS*REGION	Lower Columbia	0.00	0.08	0.00	0.9883
SPRTRANS*REGION	Mid Columbia	-0.01	0.09	0.01	0.9388
SPRTRANS*REGION	Snake	0.09	0.05	2.98	0.0841
SSTSUMR*REGION	Lower Columbia	-0.09	0.07	1.60	0.2062
SSTSUMR*REGION	Mid Columbia	-0.32	0.10	10.94	0.0009
SSTSUMR*REGION	Snake	-0.15	0.05	8.35	0.0039
SSTWINTR*REGION	Lower Columbia	-0.12	0.07	2.89	0.0889
SSTWINTR*REGION	Mid Columbia	-0.19	0.09	4.51	0.0337
SSTWINTR*REGION	Snake	-0.28	0.06	21.73	0.0001

Table 11. Estimated Parameters, Model 5 : Snake and Mid-Columbia Mus, 1959-90

Parameter	Subbasin or Region	Estimated Parameter	Std. Error	Chi-Square	P > Chi-Square
Ricker "a"	Bear Valley/Elk	4.12	0.51	65.31	0.0001
Ricker "a"	Entiat	4.53	0.79	32.68	0.0001
Ricker "a"	Imnaha	4.17	0.51	65.77	0.0001
Ricker "a"	John Day Mid Fk	2.80	0.41	46.66	0.0001
Ricker "a"	John Day Nor Fk	2.78	0.46	37.30	0.0001
Ricker "a"	John Day U Main	3.06	0.41	54.51	0.0001
Ricker "a"	Johnson	4.16	0.51	67.44	0.0001
Ricker "a"	Klickitat	1.75	0.22	62.45	0.0001
Ricker "a"	Marsh Creek	4.07	0.51	64.47	0.0001
Ricker "a"	Methow	4.90	0.81	36.25	0.0001
Ricker "a"	Minam	4.28	0.50	73.45	0.0001
Ricker "a"	Poverty Flat	4.11	0.50	67.33	0.0001
Ricker "a"	Sulphur Creek	4.32	0.50	73.89	0.0001
Ricker "a"	Warm Springs	3.36	0.38	77.11	0.0001
Ricker "a"	Wenatchee	4.13	0.82	25.15	0.0001
Ricker "a"	Wind River	1.22	0.25	24.25	0.0001
Ricker "b"	Bear Valley/Elk	0.61	0.17	12.90	0.0003
Ricker "b"	Entiat	2.42	0.61	15.64	0.0001
Ricker "b"	Imnaha	0.74	0.15	23.24	0.0001
Ricker "b"	John Day Mid Fk	1.74	0.28	39.30	0.0001
Ricker "b"	John Day Nor Fk	0.51	0.13	14.61	0.0001
Ricker "b"	John Day U Main	3.40	0.57	35.98	0.0001
Ricker "b"	Johnson	2.28	0.44	26.26	0.0001
Ricker "b"	Klickitat	2.29	0.51	20.46	0.0001
Ricker "b"	Marsh Creek	1.10	0.33	11.24	0.0008
Ricker "b"	Methow	0.70	0.17	17.15	0.0001
Ricker "b"	Minam	1.36	0.22	39.33	0.0001
Ricker "b"	Poverty Flat	0.79	0.14	33.17	0.0001
Ricker "b"	Sulphur Creek	2.01	0.43	21.36	0.0001
Ricker "b"	Warm Springs	1.56	0.30	27.69	0.0001
Ricker "b"	Wenatchee	0.30	0.12	6.32	0.0119
Ricker "b"	Wind River	2.75	0.83	10.98	0.0009

Table 11. (Continued)

Parameter	Subbasin or Region	Estimated Parameter	Std. Error	Chi-Square	P > Chi-Square
N_DAMS		-0.4473	0.15	9.38	0.00
SNA_MU59		0.1436	0.27	0.29	0.59
SNA_MU60		0.0751	0.27	0.08	0.78
SNA_MU61		0.5403	0.27	4.03	0.04
SNA_MU62		0.5546	0.26	4.42	0.04
SNA_MU63		1.0082	0.27	14.17	0.00
SNA_MU64		0.8112	0.27	9.23	0.00
SNA_MU65		0.3262	0.27	1.41	0.23
SNA_MU66		0.9615	0.27	12.83	0.00
SNA_MU67		0.5439	0.27	4.08	0.04
SNA_MU68		0.3424	0.27	1.60	0.21
SNA_MU69		1.2026	0.27	20.22	0.00
SNA_MU70		1.1937	0.27	19.58	0.00
SNA_MU71		2.2326	0.27	67.38	0.00
SNA_MU72		2.7762	0.27	107.17	0.00
SNA_MU73		0.9725	0.27	13.37	0.00
SNA_MU74		2.5272	0.28	83.51	0.00
SNA_MU75		3.6803	0.28	175.17	0.00
SNA_MU76		2.4505	0.29	73.79	0.00
SNA_MU77		2.1632	0.28	58.20	0.00
SNA_MU78		2.4803	0.27	84.43	0.00
SNA_MU79		2.2587	0.29	60.52	0.00
SNA_MU80		0.8266	0.29	7.97	0.00
SNA_MU81		1.1565	0.29	16.05	0.00
SNA_MU82		1.1922	0.29	17.06	0.00
SNA_MU83		0.4194	0.29	2.13	0.14
SNA_MU84		1.9296	0.30	40.66	0.00
SNA_MU85		2.3585	0.28	70.61	0.00
SNA_MU86		1.826	0.28	41.82	0.00
SNA_MU87		2.8408	0.28	102.96	0.00
SNA_MU88		2.1049	0.27	60.04	0.00
SNA_MU89		2.7873	0.29	92.84	0.00
SNA_MU90		4.4773	0.28	247.26	0.00

Table 11. (Concluded)

Parameter	Subbasin or Region	Estimated Parameter	Std. Error	Chi-Square	P > Chi-Square
MDC_MU59		0.2122	0.56	0.14	0.70
MDC_MU60		-0.2189	0.51	0.18	0.67
MDC_MU61		-0.2668	0.51	0.27	0.60
MDC_MU62		-0.2085	0.52	0.16	0.69
MDC_MU63		0.1866	0.51	0.13	0.71
MDC_MU64		0.0893	0.59	0.02	0.88
MDC_MU65		0.6868	0.51	1.81	0.18
MDC_MU66		0.5545	0.63	0.77	0.38
MDC_MU67		0.6301	0.54	1.39	0.24
MDC_MU68		0.4243	0.54	0.62	0.43
MDC_MU69		0.4291	0.52	0.68	0.41
MDC_MU70		0.2308	0.51	0.21	0.65
MDC_MU71		0.6567	0.51	1.66	0.20
MDC_MU72		0.8945	0.51	3.07	0.08
MDC_MU73		0.0821	0.56	0.02	0.88
MDC_MU74		0.3382	0.51	0.44	0.51
MDC_MU75		1.6117	0.53	9.22	0.00
MDC_MU76		1.0905	0.51	4.51	0.03
MDC_MU77		1.4972	0.52	8.32	0.00
MDC_MU78		1.5857	0.57	7.66	0.01
MDC_MU79		1.9748	0.51	14.84	0.00
MDC_MU80		1.5675	0.51	9.38	0.00
MDC_MU81		1.495	0.51	8.54	0.00
MDC_MU82		1.3473	0.51	6.96	0.01
MDC_MU83		1.783	0.51	12.10	0.00
MDC_MU84		2.3779	0.51	21.76	0.00
MDC_MU85		1.9178	0.52	13.46	0.00
MDC_MU86		2.3102	0.51	20.44	0.00
MDC_MU87		2.7876	0.51	30.00	0.00
MDC_MU88		2.0129	0.51	15.64	0.00
MDC_MU89		2.3816	0.51	21.76	0.00
MDC_MU90		4.6356	0.51	82.53	0.00

Table 12. Estimated Parameters, Model 6A : Drought Index, Ocean Indices + Percent Logged, Columbia-Wide Parameter on Percent Logged.

Parameter	**Subbasin or Region**	**Estimated Parameter**	**Std. Error**	**Chi-Square**	**P > Chi-Square**
Ricker "a"	Entiat	3.65	1.14	10.16	0.0014
Ricker "a"	Imnaha	4.31	0.90	22.95	0.0001
Ricker "a"	John Day Mid Fk	2.55	0.41	39.40	0.0001
Ricker "a"	John Day Nor Fk	2.90	0.57	25.52	0.0001
Ricker "a"	John Day U Main	2.82	0.40	50.76	0.0001
Ricker "a"	Klickitat	1.98	0.27	53.78	0.0001
Ricker "a"	Minam	4.64	0.96	23.40	0.0001
Ricker "a"	Wenatchee	3.70	0.76	23.93	0.0001
Ricker "a"	Wind River	1.18	0.27	18.74	0.0001
Ricker "b"	Entiat	-1.98	2.56	0.59	0.4406
Ricker "b"	Imnaha	0.78	0.27	8.19	0.0042
Ricker "b"	John Day Mid Fk	1.37	0.39	12.25	0.0005
Ricker "b"	John Day Nor Fk	0.92	0.35	6.71	0.0096
Ricker "b"	John Day U Main	2.83	0.82	11.92	0.0006
Ricker "b"	Klickitat	2.19	0.74	8.90	0.0028
Ricker "b"	Minam	2.61	0.74	12.34	0.0004
Ricker "b"	Wenatchee	-0.05	0.12	0.16	0.6849
Ricker "b"	Wind River	2.35	1.05	5.00	0.0254
N_DAMS		-0.4227	0.11	15.05	0.00
MIGRFLOW*REGION	Lower Columbia	0.06	0.10	0.33	0.5661
MIGRFLOW*REGION	Mid Columbia	0.57	0.16	13.16	0.0003
MIGRFLOW*REGION	Snake	0.20	0.13	2.33	0.1268
DR_AVG*REGION	Lower Columbia	0.09	0.10	0.79	0.3749
DR_AVG*REGION	Mid Columbia	0.31	0.17	3.57	0.0589
DR_AVG*REGION	Snake	0.43	0.14	8.79	0.003
FALTRANS*REGION	Lower Columbia	-0.03	0.09	0.13	0.7209
FALTRANS*REGION	Mid Columbia	-0.10	0.13	0.61	0.4353
FALTRANS*REGION	Snake	-0.21	0.13	2.69	0.1012
SPRTRANS*REGION	Lower Columbia	-0.04	0.11	0.14	0.7097
SPRTRANS*REGION	Mid Columbia	-0.03	0.12	0.06	0.8044
SPRTRANS*REGION	Snake	0.18	0.17	1.15	0.2842
SSTSUMR*REGION	Lower Columbia	-0.09	0.08	1.14	0.2865
SSTSUMR*REGION	Mid Columbia	-0.11	0.14	0.62	0.4297
SSTSUMR*REGION	Snake	-0.15	0.12	1.59	0.2067
SSTWINTR*REGION	Lower Columbia	-0.11	0.09	1.60	0.2062
SSTWINTR*REGION	Mid Columbia	-0.03	0.14	0.06	0.8003
SSTWINTR*REGION	Snake	-0.18	0.11	2.55	0.1105
PERTIMBR		-0.097	0.06	2.50	0.11

Table 13. Estimated Parameters, Model 6B : Drought Index, Ocean Indices + Percent Logged, Regional Parameters on Percent Logged.

Parameter	Subbasin or Region	Estimated Parameter	Std. Error	Chi-Square	P > Chi-Square
Ricker "a"	Entiat	3.62	1.15	9.98	0.0016
Ricker "a"	Imnaha	4.22	0.91	21.50	0.0001
Ricker "a"	John Day Mid Fk	2.54	0.41	39.00	0.0001
Ricker "a"	John Day Nor Fk	2.91	0.58	25.41	0.0001
Ricker "a"	John Day U Main	2.80	0.40	49.88	0.0001
Ricker "a"	Klickitat	1.97	0.27	52.90	0.0001
Ricker "a"	Minam	4.60	0.96	22.94	0.0001
Ricker "a"	Wenatchee	3.68	0.76	23.60	0.0001
Ricker "a"	Wind River	1.17	0.27	18.46	0.0001
Ricker "b"	Entiat	-1.98	2.56	0.60	0.4394
Ricker "b"	Imnaha	0.70	0.30	5.43	0.0198
Ricker "b"	John Day Mid Fk	1.37	0.39	12.27	0.0005
Ricker "b"	John Day Nor Fk	0.94	0.36	6.87	0.0088
Ricker "b"	John Day U Main	2.80	0.83	11.45	0.0007
Ricker "b"	Klickitat	2.17	0.74	8.63	0.0033
Ricker "b"	Minam	2.57	0.74	11.93	0.0006
Ricker "b"	Wenatchee	-0.05	0.12	0.16	0.6854
Ricker "b"	Wind River	2.32	1.05	4.89	0.027
N_DAMS		-0.4197	0.11	14.78	0.00
MIGRFLOW*REGION	Lower Columbia	0.05	0.10	0.29	0.5902
MIGRFLOW*REGION	Mid Columbia	0.57	0.16	13.09	0.0003
MIGRFLOW*REGION	Snake	0.21	0.13	2.46	0.1168
DR_AVG*REGION	Lower Columbia	0.09	0.10	0.79	0.3742
DR_AVG*REGION	Mid Columbia	0.31	0.17	3.19	0.0742
DR_AVG*REGION	Snake	0.42	0.14	8.59	0.0034
FALTRANS*REGION	Lower Columbia	-0.03	0.09	0.11	0.7368
FALTRANS*REGION	Mid Columbia	-0.10	0.13	0.59	0.4426
FALTRANS*REGION	Snake	-0.21	0.13	2.71	0.0997
SPRTRANS*REGION	Lower Columbia	-0.04	0.11	0.12	0.7269
SPRTRANS*REGION	Mid Columbia	-0.03	0.13	0.07	0.7983
SPRTRANS*REGION	Snake	0.16	0.17	0.85	0.3553
SSTSUMR*REGION	Lower Columbia	-0.09	0.08	1.13	0.2887
SSTSUMR*REGION	Mid Columbia	-0.11	0.14	0.61	0.4367
SSTSUMR*REGION	Snake	-0.14	0.12	1.28	0.2581
SSTWINTR*REGION	Lower Columbia	-0.11	0.09	1.53	0.2168
SSTWINTR*REGION	Mid Columbia	-0.03	0.14	0.06	0.8075
SSTWINTR*REGION	Snake	-0.17	0.11	2.45	0.1173
PERTIMBR*REGION	Lower Columbia	-0.12	0.08	2.15	0.1424
PERTIMBR*REGION	Mid Columbia	-0.10	0.12	0.79	0.3745
PERTIMBR*REGION	Snake	0.02	0.18	0.01	0.9207

Table 14. Estimated Parameters, Model 6C : Drought Index, Ocean Indices + Percent Logged, Subbasin Parameters for Percent Logged.

Parameter	Subbasin or Region	Estimated Parameter	Std. Error	Chi-Square	P > Chi-Square
Ricker "a"	Entiat	3.38	1.13	8.90	0.0028
Ricker "a"	Imnaha	4.13	0.89	21.34	0.0001
Ricker "a"	John Day Mid Fk	2.52	0.40	39.77	0.0001
Ricker "a"	John Day Nor Fk	2.90	0.62	21.94	0.0001
Ricker "a"	John Day U Main	2.78	0.40	48.17	0.0001
Ricker "a"	Klickitat	1.84	0.27	45.35	0.0001
Ricker "a"	Minam	4.50	0.94	22.80	0.0001
Ricker "a"	Wenatchee	3.59	0.74	23.36	0.0001
Ricker "a"	Wind River	1.20	0.27	19.65	0.0001
Ricker "b"	Entiat	-2.41	2.52	0.92	0.3386
Ricker "b"	Imnaha	0.70	0.29	5.63	0.0177
Ricker "b"	John Day Mid Fk	1.39	0.39	13.07	0.0003
Ricker "b"	John Day Nor Fk	0.96	0.40	5.72	0.0167
Ricker "b"	John Day U Main	2.87	0.88	10.59	0.0011
Ricker "b"	Klickitat	1.64	0.76	4.57	0.0325
Ricker "b"	Minam	2.53	0.73	12.05	0.0005
Ricker "b"	Wenatchee	-0.06	0.12	0.23	0.6348
Ricker "b"	Wind River	2.61	1.07	5.99	0.0144
N_DAMS		-0.4079	0.11	14.49	0.00
MIGRFLOW*REGION	Lower Columbia	0.04	0.10	0.19	0.6658
MIGRFLOW*REGION	Mid Columbia	0.56	0.15	13.39	0.0003
MIGRFLOW*REGION	Snake	0.21	0.13	2.62	0.1057
DR_AVG*REGION	Lower Columbia	0.07	0.11	0.41	0.5226
DR_AVG*REGION	Mid Columbia	0.25	0.18	2.06	0.1509
DR_AVG*REGION	Snake	0.42	0.14	8.95	0.0028
FALTRANS*REGION	Lower Columbia	-0.04	0.09	0.20	0.6563
FALTRANS*REGION	Mid Columbia	-0.10	0.13	0.59	0.4422
FALTRANS*REGION	Snake	-0.22	0.13	2.89	0.0893
SPRTRANS*REGION	Lower Columbia	-0.06	0.11	0.30	0.5865
SPRTRANS*REGION	Mid Columbia	0.00	0.13	0.00	0.9874
SPRTRANS*REGION	Snake	0.15	0.17	0.82	0.365
SSTSUMR*REGION	Lower Columbia	-0.09	0.08	1.19	0.2761
SSTSUMR*REGION	Mid Columbia	-0.07	0.14	0.26	0.6101
SSTSUMR*REGION	Snake	-0.14	0.12	1.33	0.2486
SSTWINTR*REGION	Lower Columbia	-0.11	0.09	1.76	0.1852
SSTWINTR*REGION	Mid Columbia	-0.01	0.13	0.01	0.9412
SSTWINTR*REGION	Snake	-0.17	0.11	2.56	0.1096
PERTIMBR*SUBBASIN	Entiat	0.16	0.21	0.63	0.4259
PERTIMBR*SUBBASIN	Imnaha	0.02	0.18	0.01	0.9154
PERTIMBR*SUBBASIN	John Day Mid Fk	-0.02	0.16	0.02	0.8846
PERTIMBR*SUBBASIN	John Day Nor Fk	-0.10	0.22	0.21	0.6436
PERTIMBR*SUBBASIN	John Day U Main	-0.10	0.15	0.46	0.4999
PERTIMBR*SUBBASIN	Klickitat	-0.52	0.20	6.71	0.0096
PERTIMBR*SUBBASIN	Wenatchee	-0.22	0.14	2.64	0.1041
PERTIMBR*SUBBASIN	Wind River	0.04	0.17	0.07	0.7973

Table 15. Comparison of Dam and Climate Parameters, Models 1-4

Model	Parameter	Region	Estimated Parameter	Std. Error	Chi-Square	P > Chi-Square
1	N_DAMS		**-0.4121**	0.04	130.63	0.00
2A	N_DAMS		**-0.4054**	0.03	135.69	0.00
	MIGRFLOW*REGION	Lower Columbia	0.12	0.08	2.26	0.1331
	MIGRFLOW*REGION	Mid Columbia	**0.44**	0.10	19.24	0.0001
	MIGRFLOW*REGION	Snake	**0.37**	0.06	42.90	0.0001
2B	N_DAMS		**-0.3685**	0.03	114.11	0.00
	DR_AVG*REGION	Lower Columbia	0.08	0.09	0.78	0.3785
	DR_AVG*REGION	Mid Columbia	**0.54**	0.11	23.67	0.0001
	DR_AVG*REGION	Snake	**0.41**	0.07	39.08	0.0001
3	N_DAMS		**-0.3722**	0.04	112.44	0.00
	MIGRFLOW*REGION	Lower Columbia	0.11	0.08	1.96	0.1617
	MIGRFLOW*REGION	Mid Columbia	**0.37**	0.10	13.82	0.0002
	MIGRFLOW*REGION	Snake	**0.24**	0.06	14.31	0.0002
	DR_AVG*REGION	Lower Columbia	0.05	0.09	0.29	0.5882
	DR_AVG*REGION	Mid Columbia	**0.45**	0.11	16.51	0.0001
	DR_AVG*REGION	Snake	**0.27**	0.08	12.22	0.0005
4	N_DAMS		-0.3646	0.03	115.94	0.00
	MIGRFLOW*REGION	Lower Columbia	0.16	0.08	4.52	0.0335
	MIGRFLOW*REGION	Mid Columbia	**0.47**	0.10	21.52	0.0001
	MIGRFLOW*REGION	Snake	**0.16**	0.06	6.74	0.0095
	DR_AVG*REGION	Lower Columbia	-0.01	0.09	0.01	0.9118
	DR_AVG*REGION	Mid Columbia	**0.36**	0.11	10.69	0.0011
	DR_AVG*REGION	Snake	**0.41**	0.08	28.22	0.0001
	FALTRANS*REGION	Lower Columbia	**-0.16**	0.07	4.96	0.0259
	FALTRANS*REGION	Mid Columbia	-0.11	0.10	1.19	0.2747
	FALTRANS*REGION	Snake	**-0.27**	0.06	20.15	0.0001
	SPRTRANS*REGION	Lower Columbia	0.00	0.08	0.00	0.9883
	SPRTRANS*REGION	Mid Columbia	-0.01	0.09	0.01	0.9388
	SPRTRANS*REGION	Snake	0.09	0.05	2.98	0.0841
	SSTSUMR*REGION	Lower Columbia	-0.09	0.07	1.60	0.2062
	SSTSUMR*REGION	Mid Columbia	**-0.32**	0.10	10.94	0.0009
	SSTSUMR*REGION	Snake	**-0.15**	0.05	8.35	0.0039
	SSTWINTR*REGION	Lower Columbia	-0.12	0.07	2.89	0.0889
	SSTWINTR*REGION	Mid Columbia	**-0.19**	0.09	4.51	0.0337
	SSTWINTR*REGION	Snake	**-0.28**	0.06	21.73	0.0001

Table 16. Average "N*" (Effective Degrees of Freedom) for Independent Variables

Independent Variable	Average "N"	Average "N*" Corrected for Autocorrelation	Ratio, N*/N
SPAWNERS	30.13	15.62	0.52
N_DAMS	30.13	8.15	0.27
DR_AVG	30.13	16.84	0.56
MIGRFLOW	30.13	19.18	0.64
FALTRANS	30.13	24.85	0.82
SPRTRANS	30.13	21.78	0.72
SSTSUMR	30.13	29.27	0.97
SSTWINTR	30.13	23.15	0.77

Table 17: Significance of N_DAMS and Climate Variables at Lower EDF

Model	Parameter	Region	Estimated Parameter	Std. Error	t-ratio	Prob > T, 496 DOF	Prob. > T, 150 DOF	Prob. > T, 100 DOF	Prob. > T, 50 DOF
1	**N_DAMS**		**-0.4121**	0.04	11.42	**5.70E-27**	**4.07E-22**	**8.04E-20**	**1.55E-15**
2A	**N_DAMS**		**-0.4054**	0.03	11.65	**6.67E-28**	**9.64E-23**	**2.51E-20**	**7.39E-16**
	MIGRFLOW*REGION	**Lower Columbia**	0.12	0.08	1.50	1.34E-01	1.35E-01	1.36E-01	1.40E-01
	MIGRFLOW*REGION	**Mid Columbia**	**0.44**	0.10	4.39	**1.41E-05**	**2.17E-05**	**2.86E-05**	**5.96E-05**
	MIGRFLOW*REGION	**Snake**	**0.37**	0.06	6.54	**1.48E-10**	**8.89E-10**	**2.58E-09**	**3.10E-08**
2B	**N_DAMS**		**-0.3685**	0.03	10.68	**6.89E-24**	**3.69E-20**	**3.19E-18**	**1.67E-14**
	DR_AVG*REGION	**Lower Columbia**	0.08	0.09	0.88	3.79E-01	3.80E-01	3.81E-01	3.83E-01
	DR_AVG*REGION	**Mid Columbia**	**0.54**	0.11	4.87	**1.58E-06**	**2.86E-06**	**4.27E-06**	**1.18E-05**
	DR_AVG*REGION	**Snake**	**0.41**	0.07	6.25	**9.66E-10**	**4.09E-09**	**1.02E-08**	**9.01E-08**
3	**N_DAMS**		**-0.3722**	0.04	10.60	**1.34E-23**	**5.92E-20**	**4.71E-18**	**2.15E-14**
	MIGRFLOW*REGION	**Lower Columbia**	0.11	0.08	1.40	1.63E-01	1.64E-01	1.65E-01	1.68E-01
	MIGRFLOW*REGION	**Mid Columbia**	**0.37**	0.10	3.72	**2.26E-04**	**2.83E-04**	**3.31E-04**	**5.08E-04**
	MIGRFLOW*REGION	**Snake**	**0.24**	0.06	3.78	**1.75E-04**	**2.22E-04**	**2.62E-04**	**4.13E-04**
	DR_AVG*REGION	**Lower Columbia**	0.05	0.09	0.54	5.89E-01	5.89E-01	5.90E-01	5.91E-01
	DR_AVG*REGION	**Mid Columbia**	**0.45**	0.11	4.06	**5.71E-05**	**7.78E-05**	**9.64E-05**	**1.71E-04**
	DR_AVG*REGION	**Snake**	**0.27**	0.08	3.49	**5.23E-04**	**6.25E-04**	**7.10E-04**	**1.01E-03**
4	**N_DAMS**		**-0.3646**	0.03	10.76	**3.64E-24**	**2.35E-20**	**2.20E-18**	**1.31E-14**
	MIGRFLOW*REGION	**Lower Columbia**	**0.16**	0.08	2.13	**3.41E-02**	**3.52E-02**	**3.60E-02**	**3.85E-02**
	MIGRFLOW*REGION	**Mid Columbia**	**0.47**	0.10	4.64	**4.58E-06**	**7.54E-06**	**1.06E-05**	**2.54E-05**
	MIGRFLOW*REGION	**Snake**	**0.16**	0.06	2.60	**9.73E-03**	**1.04E-02**	**1.08E-02**	**1.23E-02**
	DR_AVG*REGION	**Lower Columbia**	-0.01	0.09	0.11	9.12E-01	9.12E-01	9.12E-01	9.12E-01
	DR_AVG*REGION	**Mid Columbia**	**0.36**	0.11	3.27	**1.15E-03**	**1.33E-03**	**1.47E-03**	**1.95E-03**
	DR_AVG*REGION	**Snake**	**0.41**	0.08	5.31	**1.70E-07**	**3.84E-07**	**6.57E-07**	**2.51E-06**
	FALTRANS*REGION	**Lower Columbia**	**-0.16**	0.07	2.23	**2.63E-02**	**2.73E-02**	**2.81E-02**	**3.04E-02**
	FALTRANS*REGION	**Mid Columbia**	-0.11	0.10	1.09	2.75E-01	2.76E-01	2.77E-01	2.80E-01
	FALTRANS*REGION	**Snake**	**-0.27**	0.06	4.49	**9.24E-06**	**1.44E-05**	**1.94E-05**	**4.27E-05**
	SPRTRANS*REGION	**Lower Columbia**	0.00	0.08	0.01	9.89E-01	9.89E-01	9.89E-01	9.89E-01
	SPRTRANS*REGION	**Mid Columbia**	-0.01	0.09	0.08	9.38E-01	9.39E-01	9.39E-01	9.39E-01
	SPRTRANS*REGION	**Snake**	0.09	0.05	1.73	8.48E-02	8.62E-02	8.72E-02	9.03E-02
	SSTSUMR*REGION	**Lower Columbia**	-0.09	0.07	1.26	2.07E-01	2.08E-01	2.09E-01	2.12E-01
	SSTSUMR*REGION	**Mid Columbia**	**-0.32**	0.10	3.31	**1.02E-03**	**1.18E-03**	**1.31E-03**	**1.75E-03**
	SSTSUMR*REGION	**Snake**	**-0.15**	0.05	2.89	**4.06E-03**	**4.44E-03**	**4.74E-03**	**5.70E-03**
	SSTWINTR*REGION	**Lower Columbia**	-0.12	0.07	1.70	8.95E-02	9.08E-02	9.19E-02	9.50E-02
	SSTWINTR*REGION	**Mid Columbia**	**-0.19**	0.09	2.12	**3.43E-02**	**3.54E-02**	**3.62E-02**	**3.87E-02**
	SSTWINTR*REGION	**Snake**	**-0.28**	0.06	4.66	**4.22E-06**	**6.99E-06**	**9.86E-06**	**2.40E-05**

Table 18. Significance of NDAMS and Climate With Inflated Standard Errors

Model	**Parameter**	**Region**	**Estimated Parameter**	**Std. Error**	**t-ratio**	**Prob > t**	**Std. Error Expansion Factor**	**Expanded t-ratio**	**Prob > t**
1	**N_DAMS**		**-0.4121**	0.04	11.42	**1.11E-26**	1.63	7.01	**8.82E-12**
2A	**N_DAMS**		**-0.4054**	0.03	11.65	**1.36E-27**	1.39	8.39	**6.45E-16**
	MIGRFLOW*REGION	**Lower Columbia**	0.12	0.08	1.50	1.34E-01	1.39	1.08	2.80E-01
	MIGRFLOW*REGION	**Mid Columbia**	**0.44**	0.10	4.39	**1.44E-05**	1.39	3.16	**1.70E-03**
	MIGRFLOW*REGION	**Snake**	**0.37**	0.06	6.54	**1.63E-10**	1.39	4.71	**3.27E-06**
2B	**N_DAMS**		**-0.3685**	0.03	10.68	**6.89E-24**	1.39	7.66	**1.16E-13**
	DR_AVG*REGION	**Lower Columbia**	0.08	0.09	0.88	3.79E-01	1.39	0.63	5.28E-01
	DR_AVG*REGION	**Mid Columbia**	**0.54**	0.11	4.87	**1.58E-06**	1.39	3.49	**5.34E-04**
	DR_AVG*REGION	**Snake**	**0.41**	0.07	6.25	**9.66E-10**	1.39	4.48	**9.49E-06**
3	**N_DAMS**		**-0.3722**	0.04	10.60	**1.34E-23**	1.35	7.84	**3.38E-14**
	MIGRFLOW*REGION	**Lower Columbia**	0.11	0.08	1.40	1.63E-01	1.35	1.03	3.02E-01
	MIGRFLOW*REGION	**Mid Columbia**	**0.37**	0.10	3.72	**2.26E-04**	1.35	2.75	**6.24E-03**
	MIGRFLOW*REGION	**Snake**	**0.24**	0.06	3.78	**1.75E-04**	1.35	2.80	**5.38E-03**
	DR_AVG*REGION	**Lower Columbia**	0.05	0.09	0.54	5.89E-01	1.35	0.40	6.89E-01
	DR_AVG*REGION	**Mid Columbia**	**0.45**	0.11	4.06	**5.71E-05**	1.35	3.00	**2.82E-03**
	DR_AVG*REGION	**Snake**	**0.27**	0.08	3.49	**5.23E-04**	1.35	2.58	**1.01E-02**
4	**N_DAMS**		**-0.3646**	0.03	10.76	**3.64E-24**	1.30	8.25	**1.76E-15**
	MIGRFLOW*REGION	**Lower Columbia**	**0.16**	0.08	2.13	**3.41E-02**	1.30	1.63	**1.04E-01**
	MIGRFLOW*REGION	**Mid Columbia**	**0.47**	0.10	4.64	**4.58E-06**	1.30	3.56	**4.11E-04**
	MIGRFLOW*REGION	**Snake**	**0.16**	0.06	2.60	**9.73E-03**	1.30	1.99	**4.70E-02**
	DR_AVG*REGION	**Lower Columbia**	-0.01	0.09	0.11	9.12E-01	1.30	0.08	9.32E-01
	DR_AVG*REGION	**Mid Columbia**	**0.36**	0.11	3.27	**1.15E-03**	1.30	2.51	**1.25E-02**
	DR_AVG*REGION	**Snake**	**0.41**	0.08	5.31	**1.70E-07**	1.30	4.08	**5.44E-05**
	FALTRANS*REGION	**Lower Columbia**	**-0.16**	0.07	2.23	**2.63E-02**	1.30	1.71	**8.80E-02**
	FALTRANS*REGION	**Mid Columbia**	-0.11	0.10	1.09	2.75E-01	1.30	0.84	4.02E-01
	FALTRANS*REGION	**Snake**	**-0.27**	0.06	4.49	**9.24E-06**	1.30	3.44	**6.34E-04**
	SPRTRANS*REGION	**Lower Columbia**	0.00	0.08	0.01	9.89E-01	1.30	0.01	9.91E-01
	SPRTRANS*REGION	**Mid Columbia**	-0.01	0.09	0.08	9.38E-01	1.30	0.06	9.53E-01
	SPRTRANS*REGION	**Snake**	0.09	0.05	1.73	8.48E-02	1.30	1.32	1.86E-01
	SSTSUMR*REGION	**Lower Columbia**	-0.09	0.07	1.26	2.07E-01	1.30	0.97	3.33E-01
	SSTSUMR*REGION	**Mid Columbia**	**-0.32**	0.10	3.31	**1.02E-03**	1.30	2.54	**1.15E-02**
	SSTSUMR*REGION	**Snake**	**-0.15**	0.05	2.89	**4.06E-03**	1.30	2.22	**2.72E-02**
	SSTWINTR*REGION	**Lower Columbia**	-0.12	0.07	1.70	8.95E-02	1.30	1.31	1.92E-01
	SSTWINTR*REGION	**Mid Columbia**	**-0.19**	0.09	2.12	3.43E-02	1.30	1.63	1.04E-01
	SSTWINTR*REGION	**Snake**	**-0.28**	0.06	4.66	**4.22E-06**	1.30	3.57	**3.91E-04**

Figure 1. Regional Drought Indices (Smoothed).

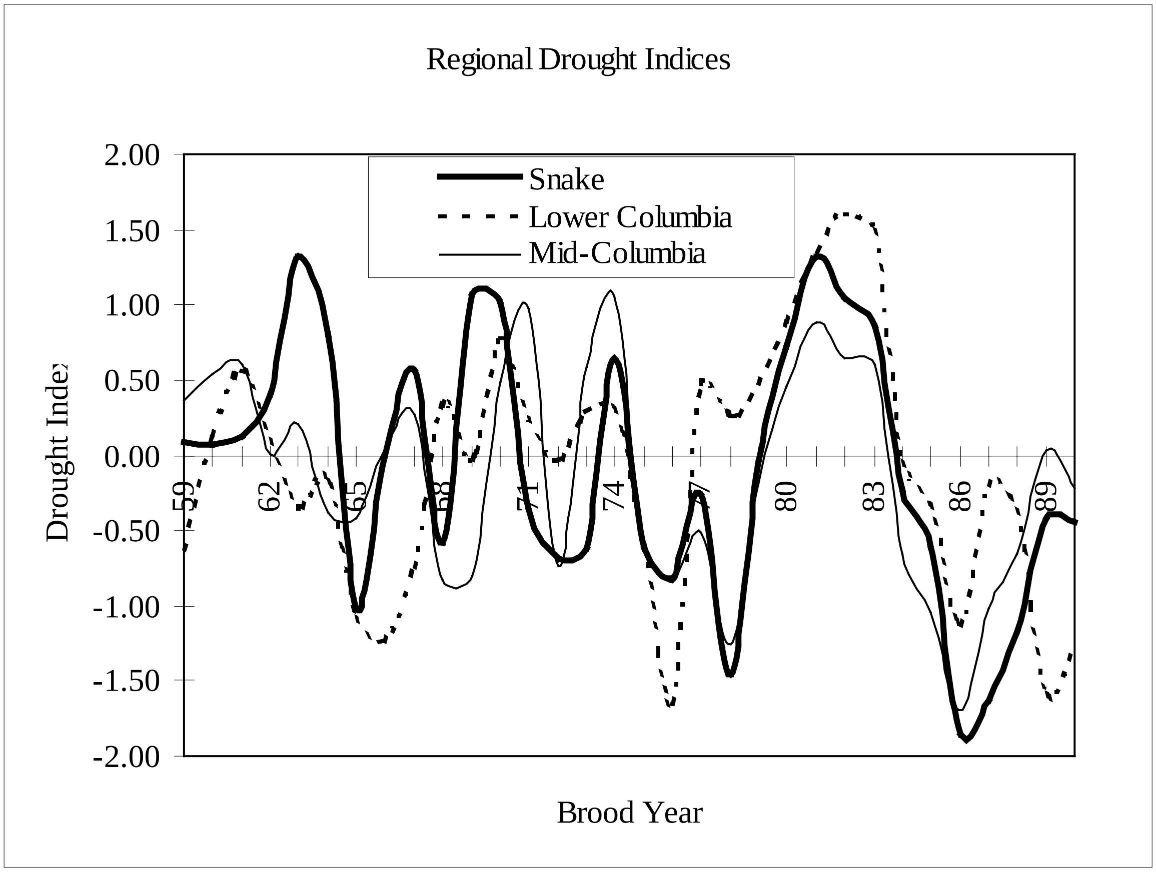


Figure 2. Regional Migration Flow Indices (Smoothed)

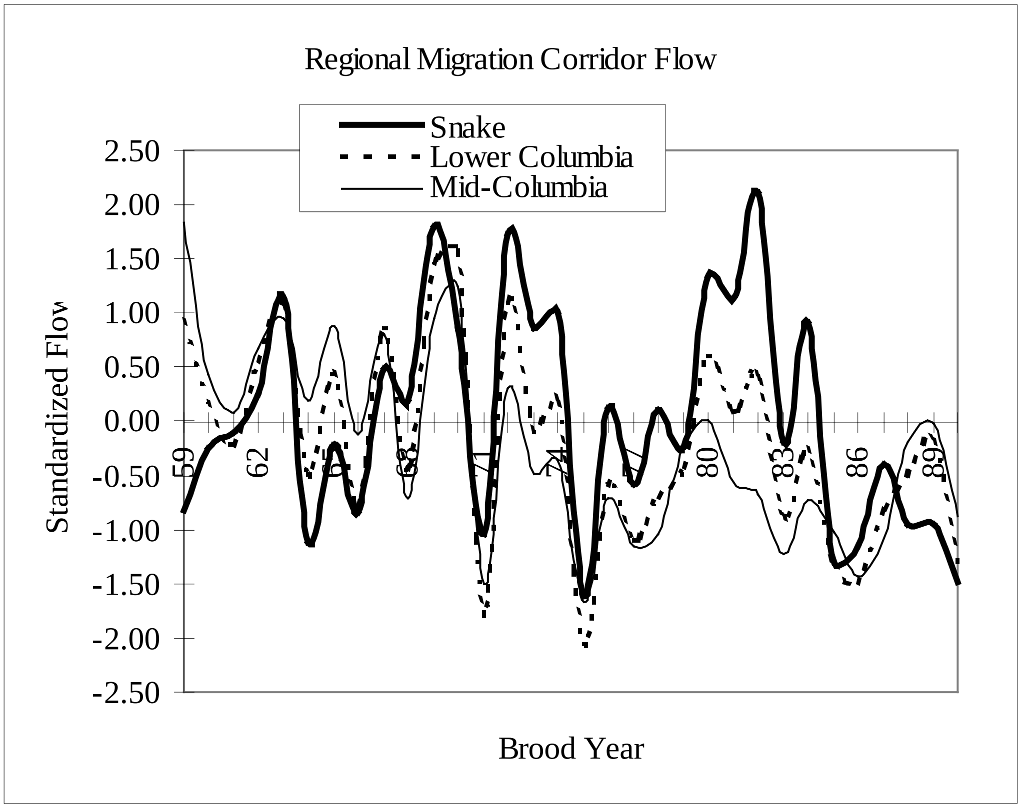


Figure 3A. Summer Sea Surface Temperatures (Smoothed)

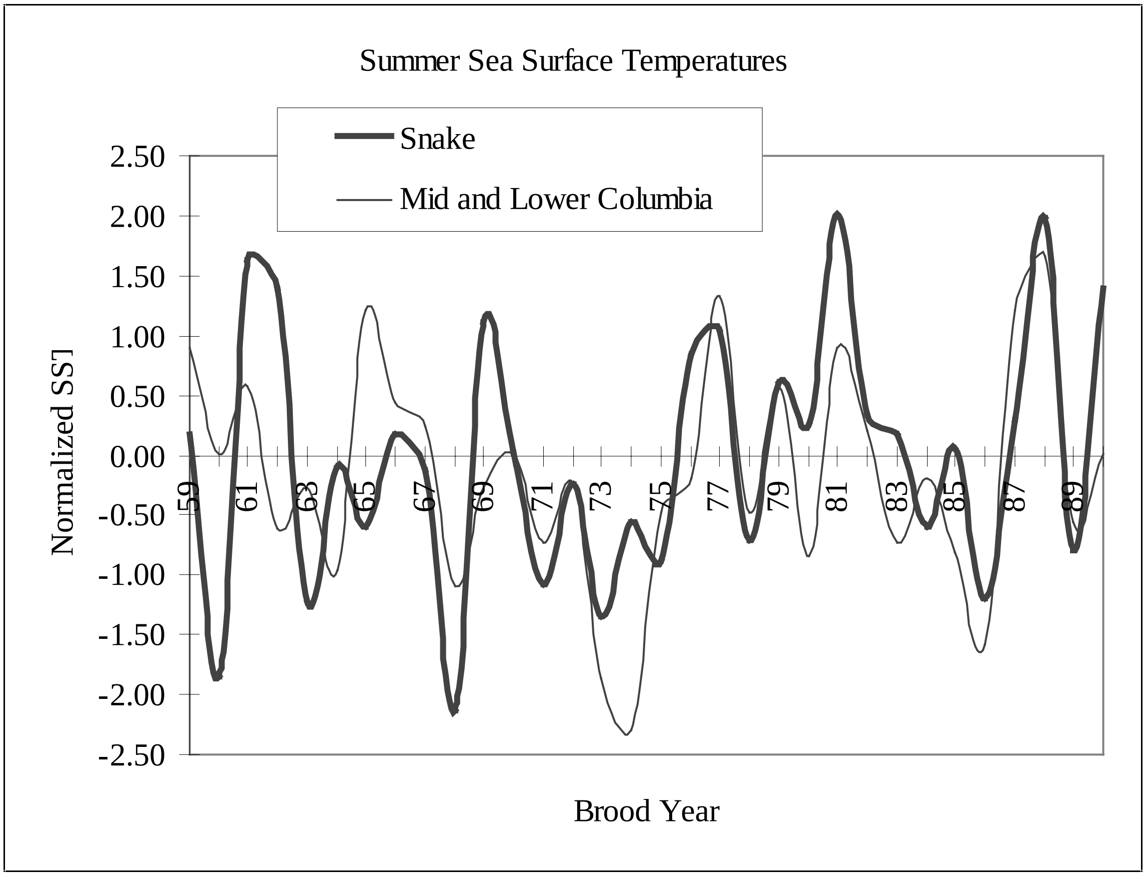


Figure 3B. Winter Sea Surface Temperatures (Smoothed)

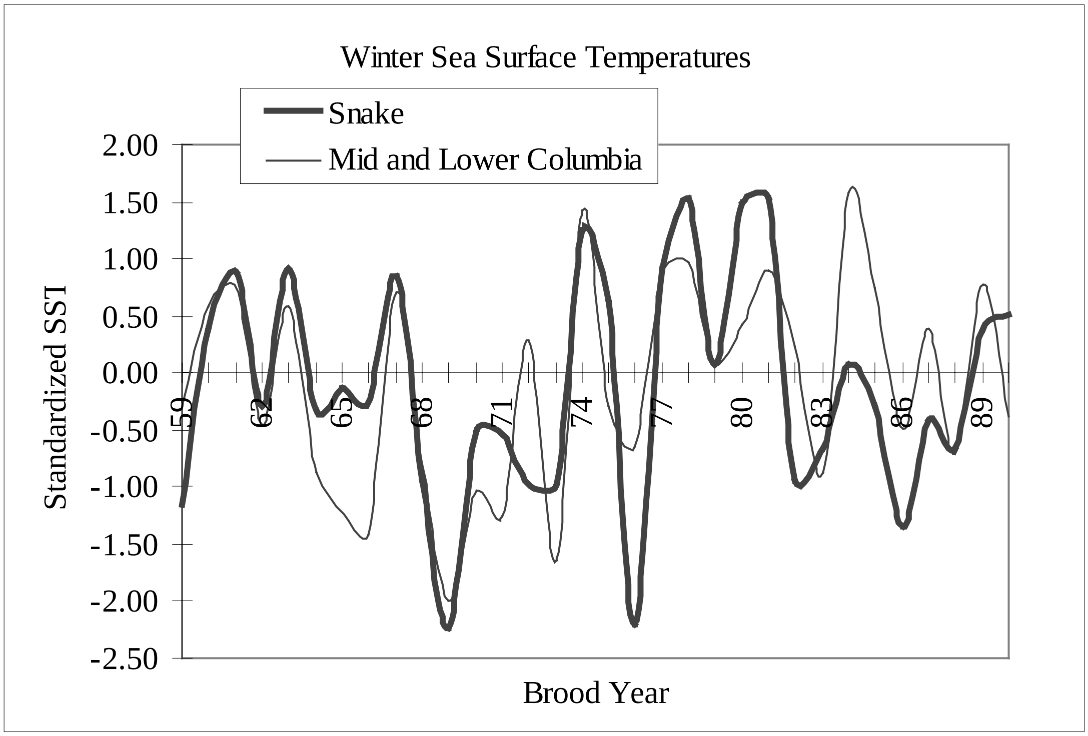


Figure 4. Spring and Fall Transition Dates (Smoothed).

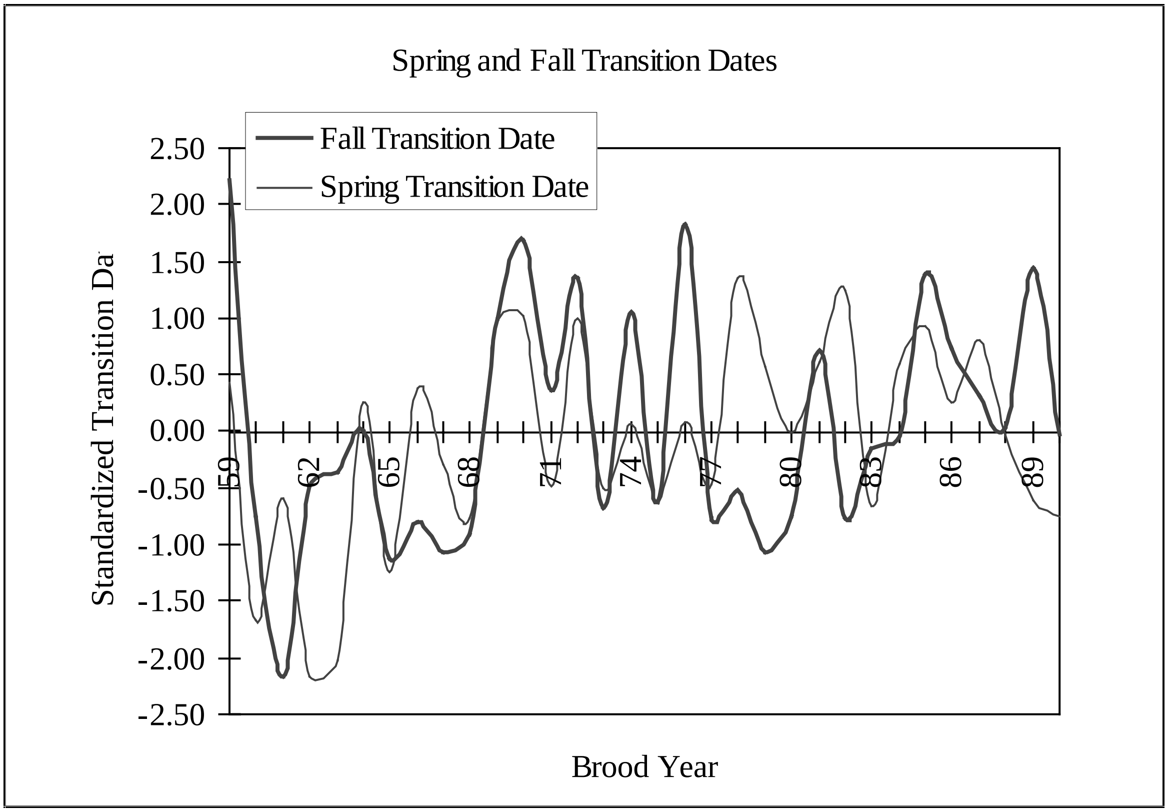


Figure 5. Normality Plot, Model 4 Residuals

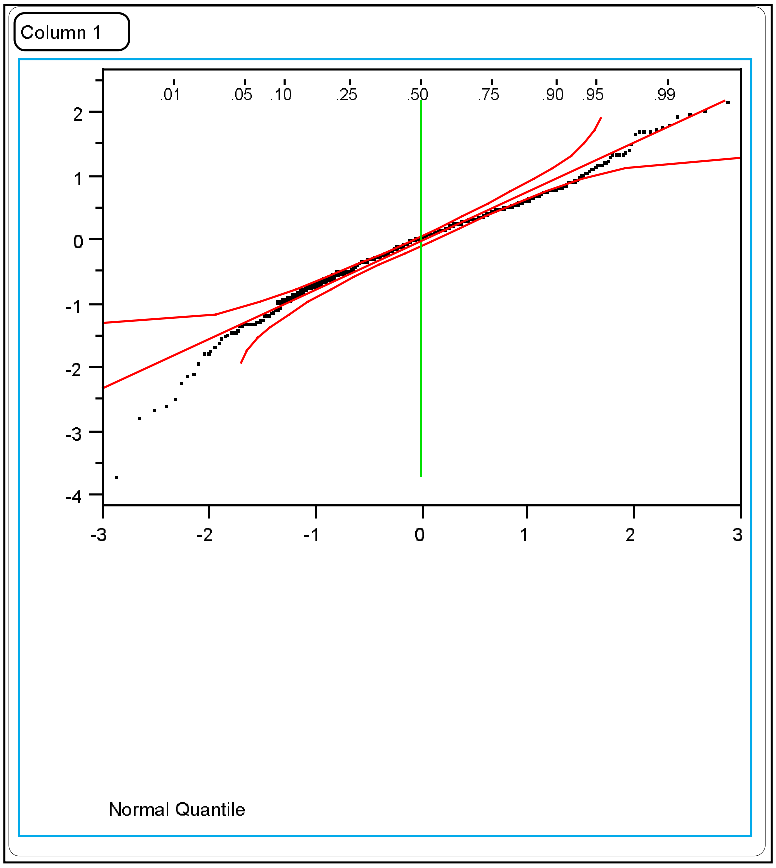


Figure 6A. Model 4 (Climate) vs. Model 5 μs - Snake River Stocks (Smoothed)

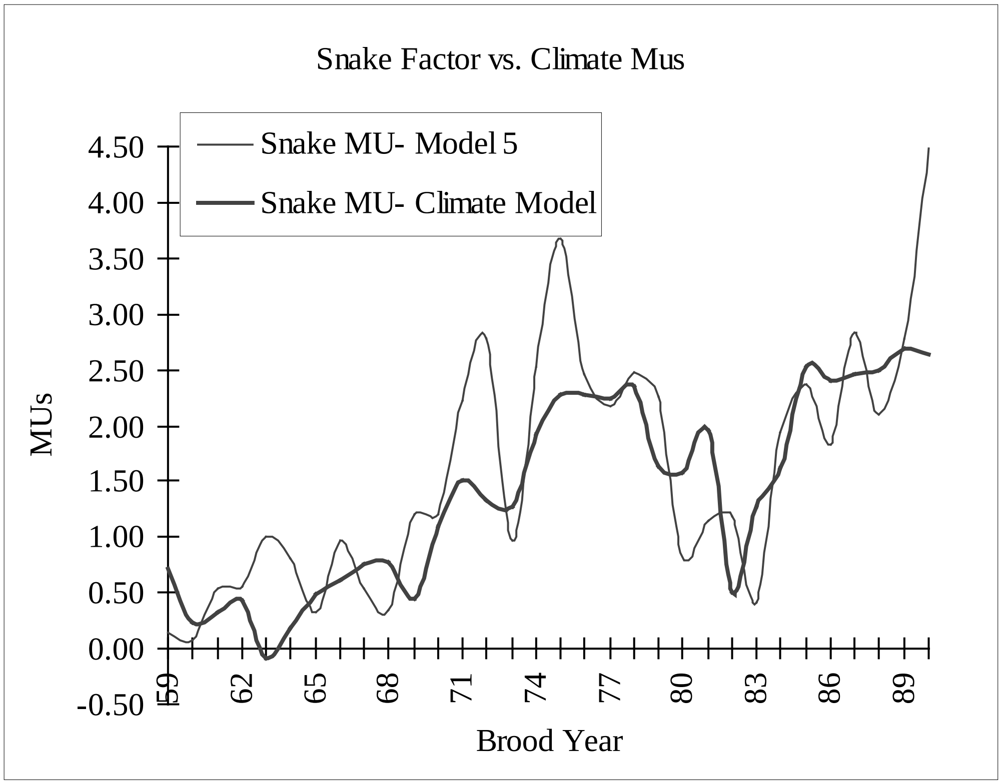


Figure 6B. Model 4 (Climate) vs. Model 5 μs - Mid-Columbia Stocks (Smoothed).

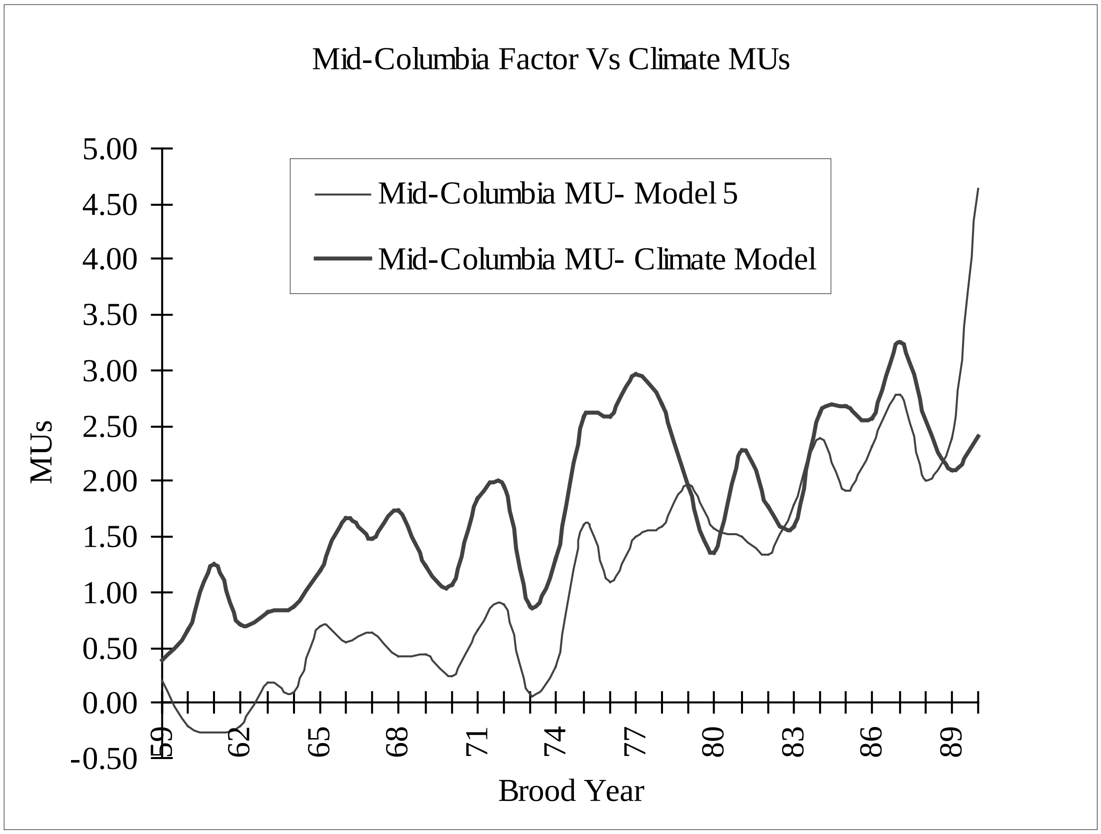
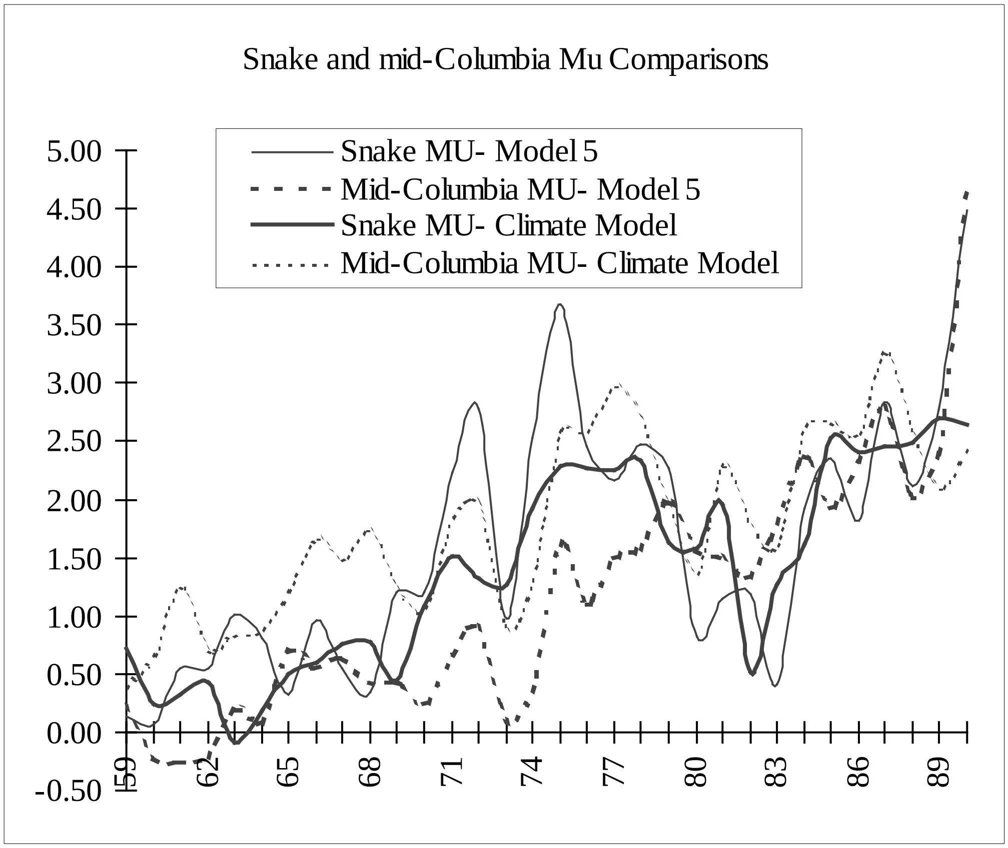


Figure 7. Comparison of Snake and Mid-Columbia Mus from Climate (Model 4) and Factor (Model 5) Models (Smoothed)



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